

Two sources of uncertainty in retrieval of ice cloud properties

Qingyuan Han
University of Alabama in Huntsville

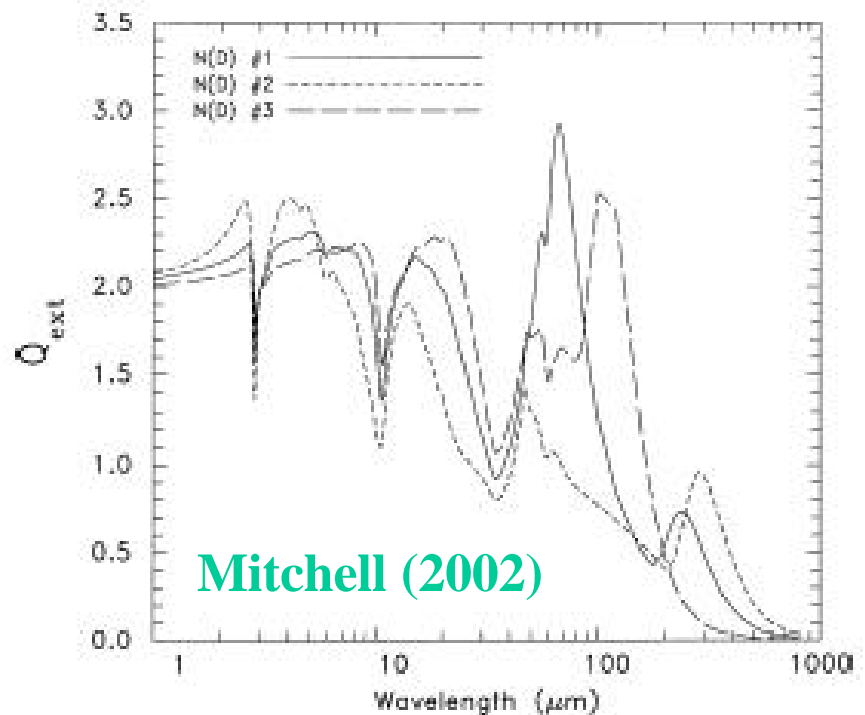
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Outline

- Empirical size distributions assumed in algorithms and the associated problem
- Solution: theoretical size distributions
- Crystal habits used in algorithms and the possible effects
- Deriving crystal habits using CERES biaxial mode (RAP) data

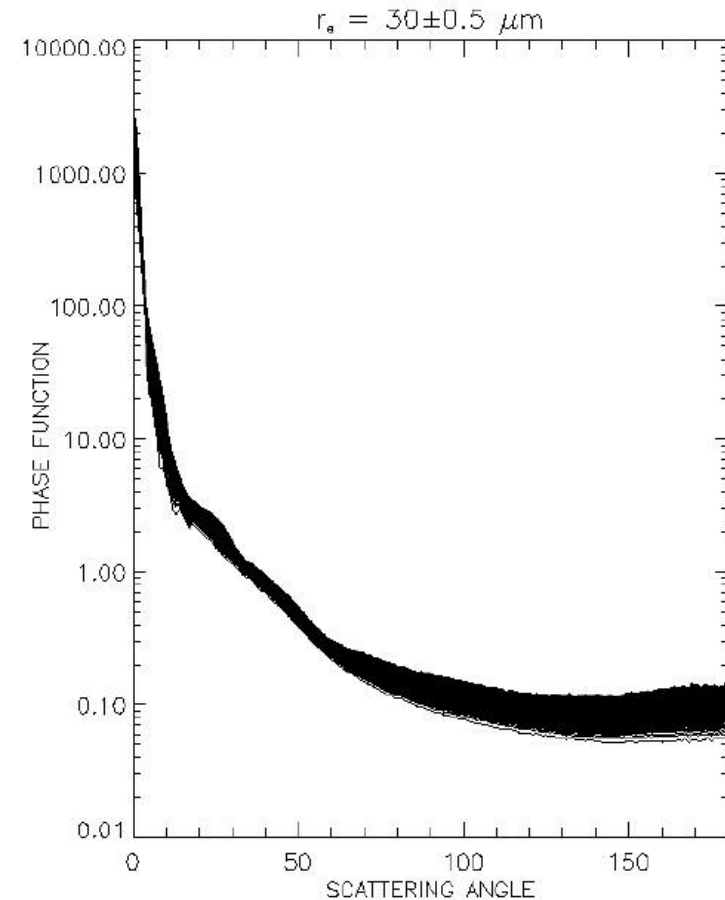
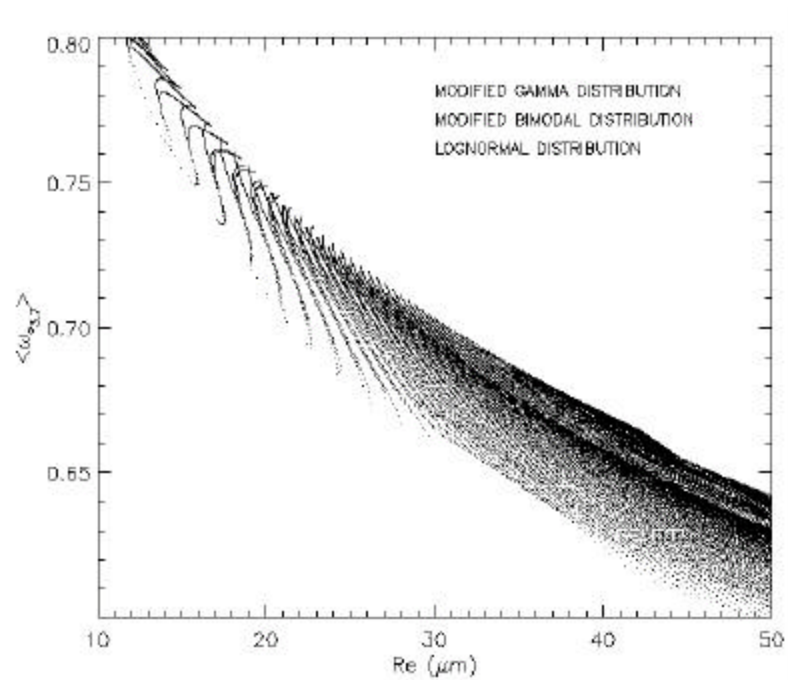
Different approaches for ice and water clouds

- For water clouds: theoretical size distributions characterized by two size parameters: r_e and v_e are used (Hansen and Travis 1974).
- For ice clouds: empirical size distributions characterized by one size parameter: r_e or D_e were adopted (Fu 1996, Wyser & Yang 1998).



- The ad hoc choice of empirical size distributions may cause large uncertainties in the retrieved ice cloud properties

Effects of size distribution on Single Scattering Properties



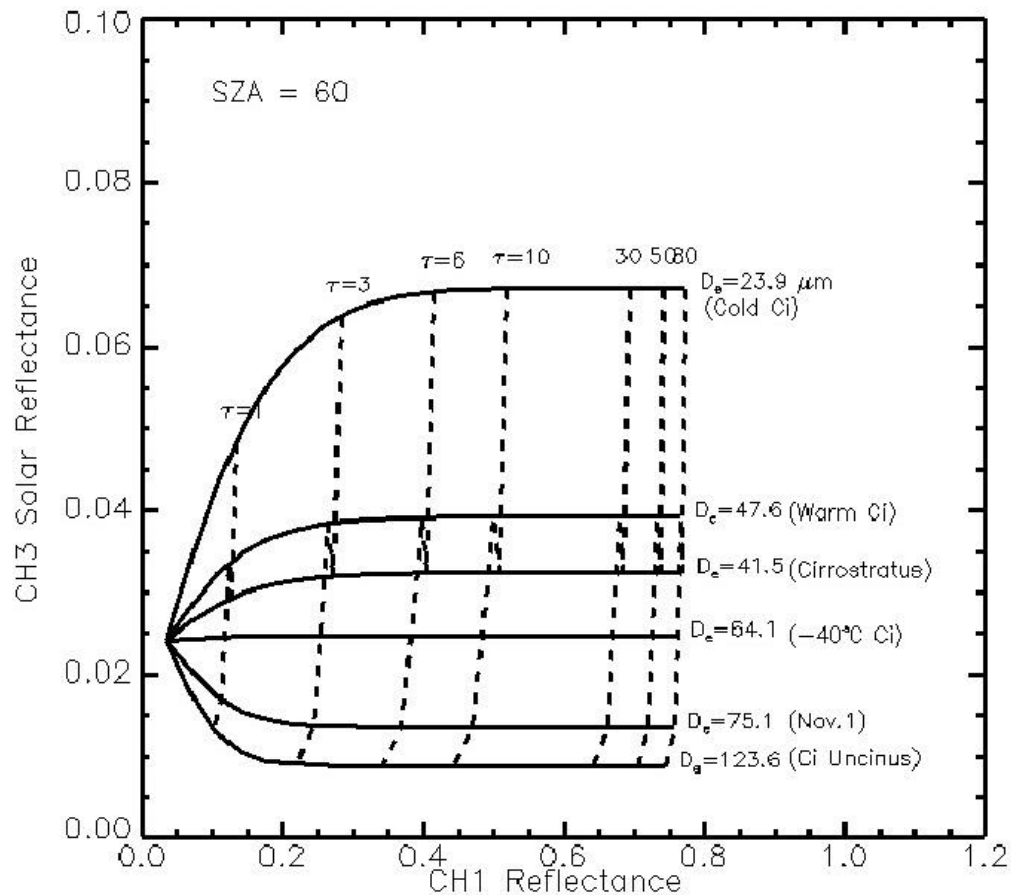
- For the same effective size, different size distributions cause large range of variations in single scattering properties

Inconsistent single scattering properties

Cloud Model	v_e	CERES ($\lambda = 3.73 \text{ mm}$)			MODIS ($\lambda = 3.82 \text{ mm}$)		
		$D_e \text{ (mm)}$	V_o	g	$r_e \text{ (mm)}$	V_o	g
Cold Cirrus	0.85	23.86	0.7849	0.8057	8.9	0.7924	0.7840
Cirrosstratus	0.52	41.20	0.7047	0.8571	19.3	0.7924	0.7840
Warm Cirrus	0.96	45.30	0.7176	0.8469	26.3	0.7927	0.7777
-40° Cirrus	0.95	67.60	0.6775	0.8731	37.3	0.7376	0.8257
Nov. 1 Cirrus	0.18	75.20	0.6281	0.9121			
Cirrusuncinus	0.15	123.1	0.5875	0.9344	78.5	0.6347	0.9242

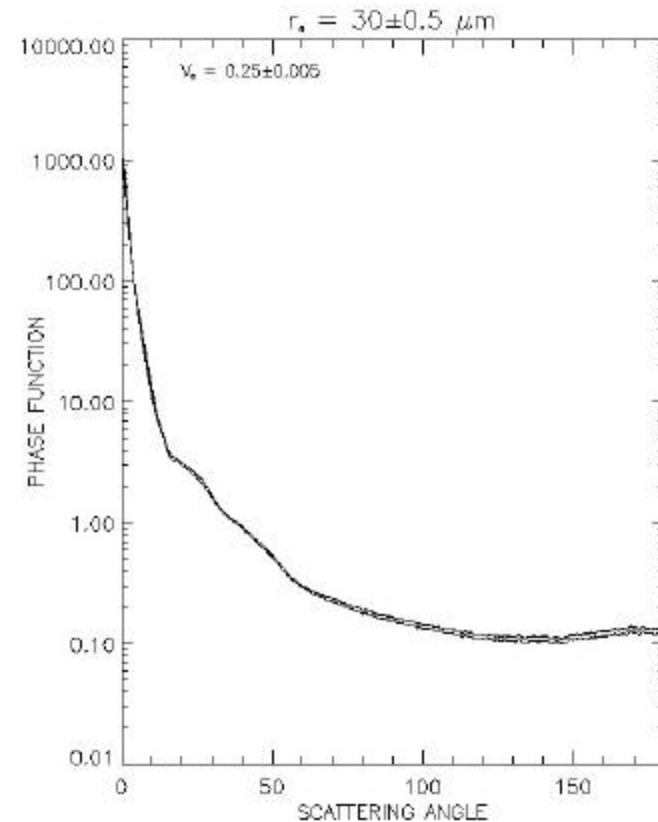
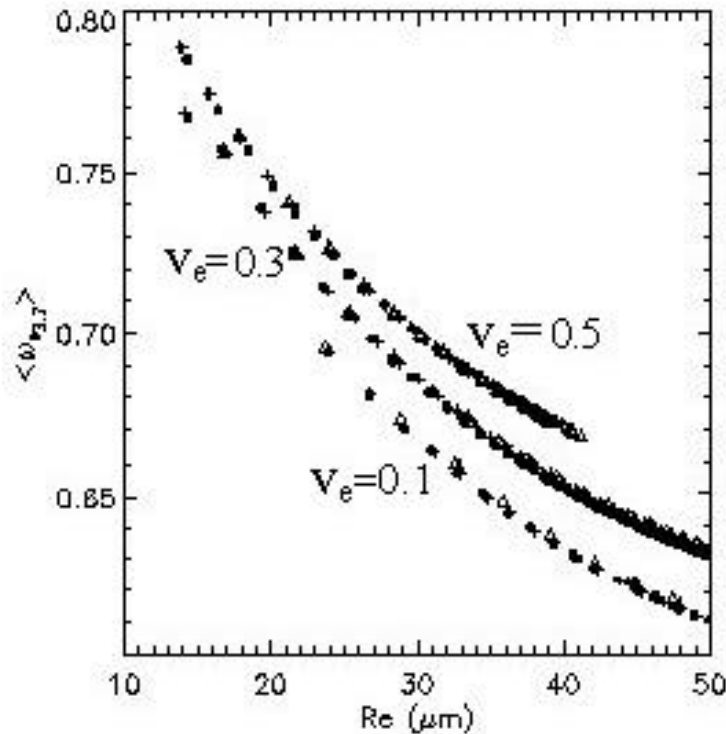
- Variations of size distribution shapes lead to non-monotonic behavior of single scattering properties with particle size.**

Multiple solution problem



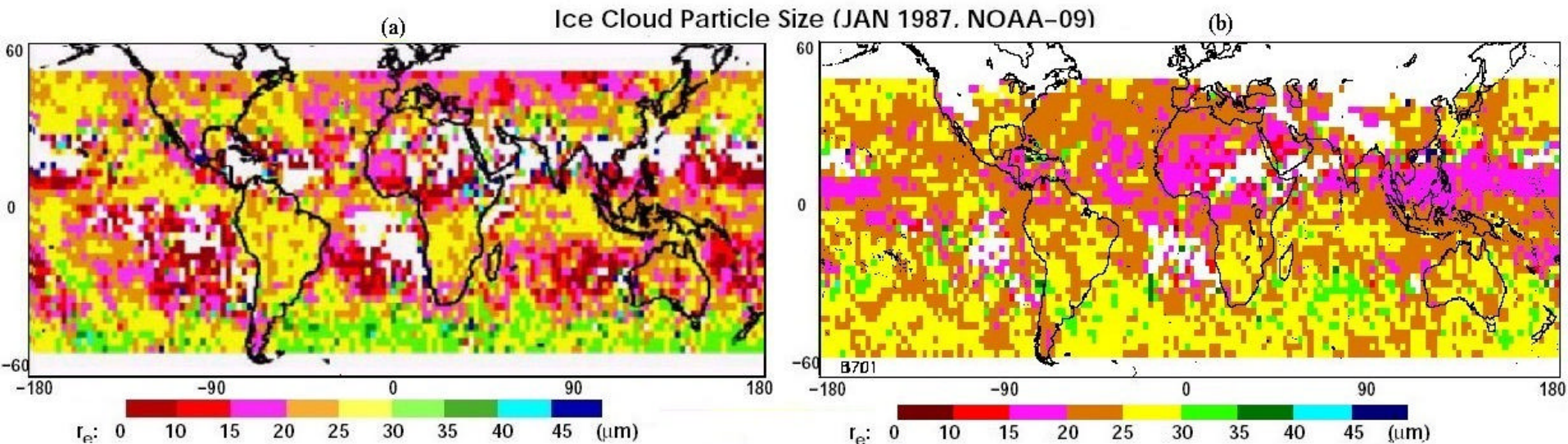
- Inconsistent behavior of single scattering properties may cause problem of multiple solutions and inconsistency.

Single scattering properties with fixed v_e



- For a given pair of r_e and v_e , single scattering properties are independent of size distributions

Retrievals using theoretical and empirical size distributions



- Retrieved r_e using empirical (left panel) and theoretical (right panel) size distributions

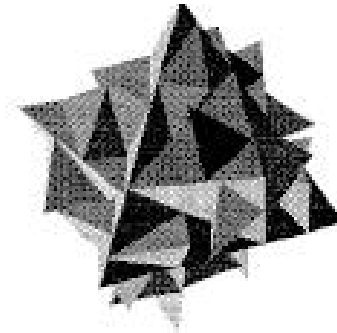
Various crystal habits assumed in satellite retrievals

CERES



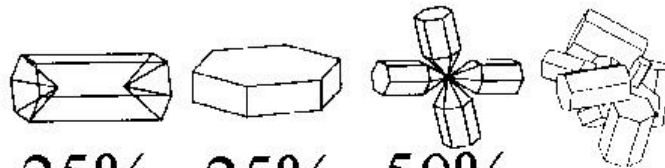
Minnis et al. (1998)

ISCCP



Rossow et al. (1996)

MODIS



$D < 70 \mu\text{m}$

25%

25%

50%

$D > 70 \mu\text{m}$

30%

20%

20%

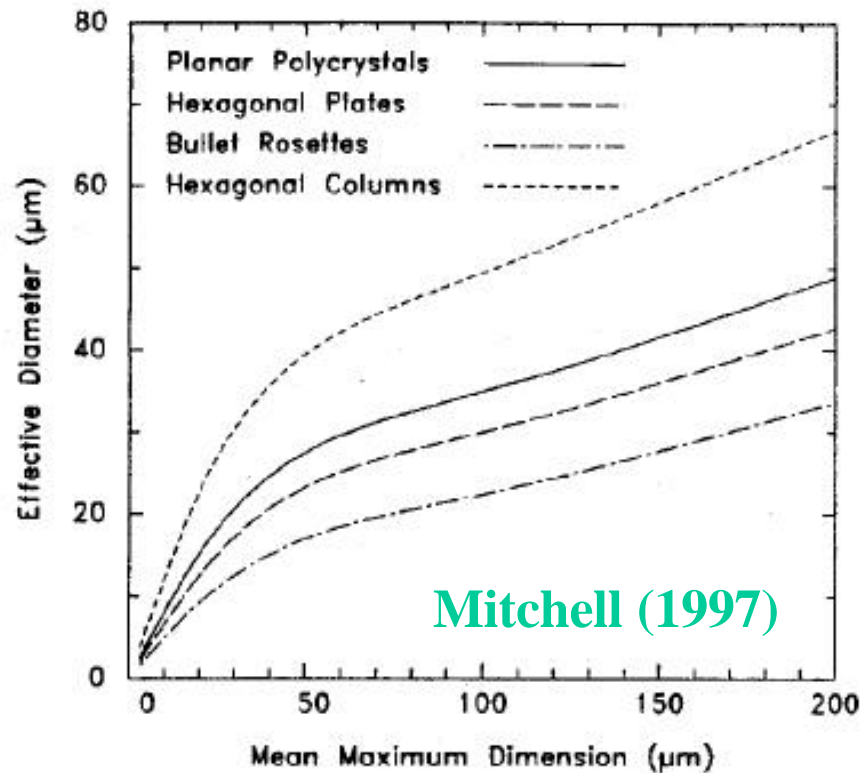
30%

Baum et al. 2000

POLDER: Modified VVP (Doutriaux-Boucher et al. 2000)

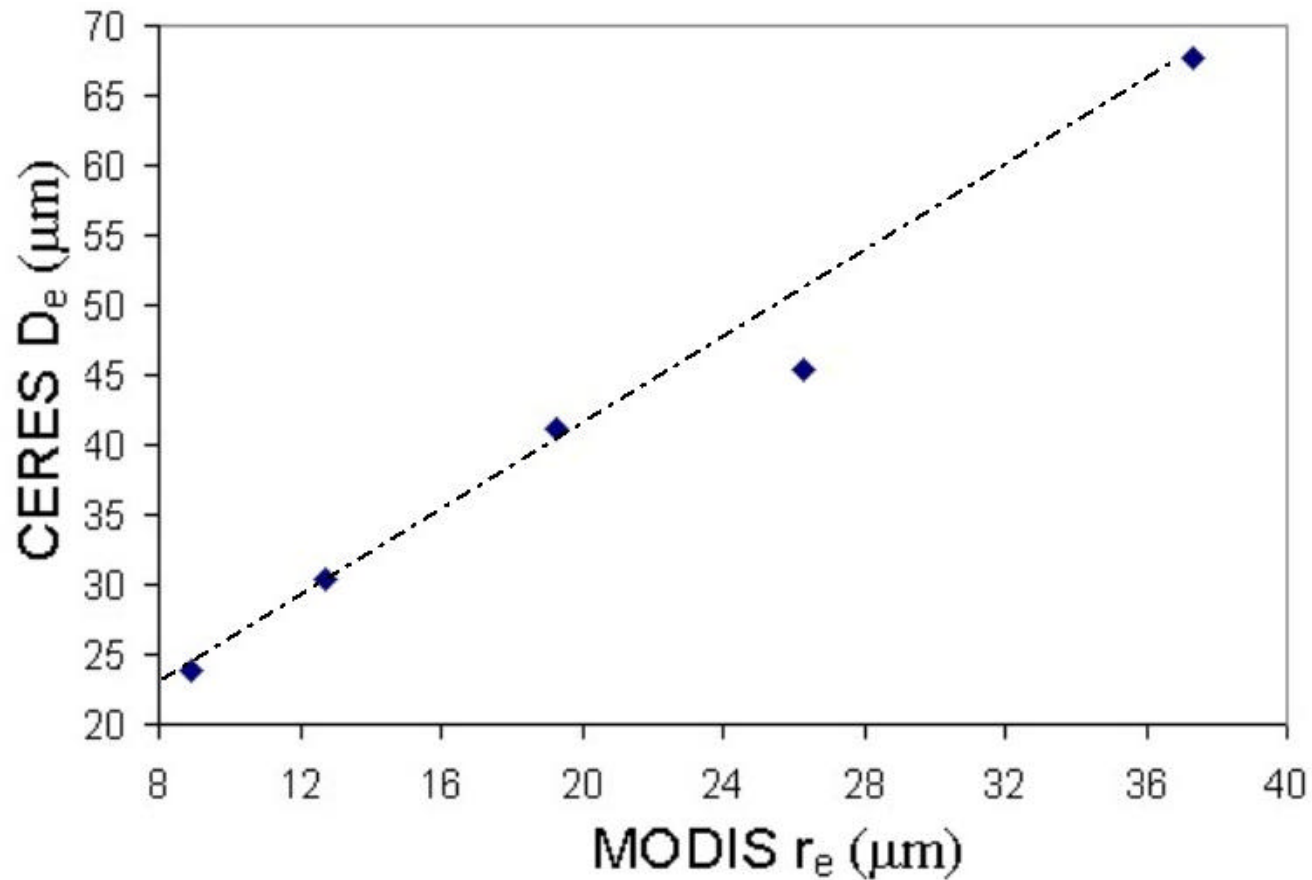
- In all algorithms, one habit assumption is used for all ice-clouds

Effects on effective particle size



- For the same maximum dimension of crystals, different shapes may lead to uncertainties of effective size by a factor of two.

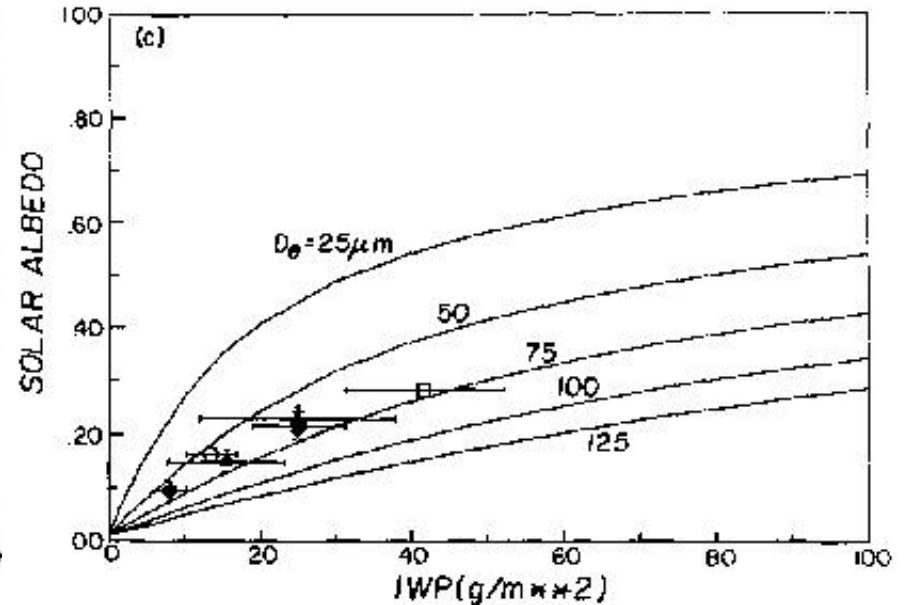
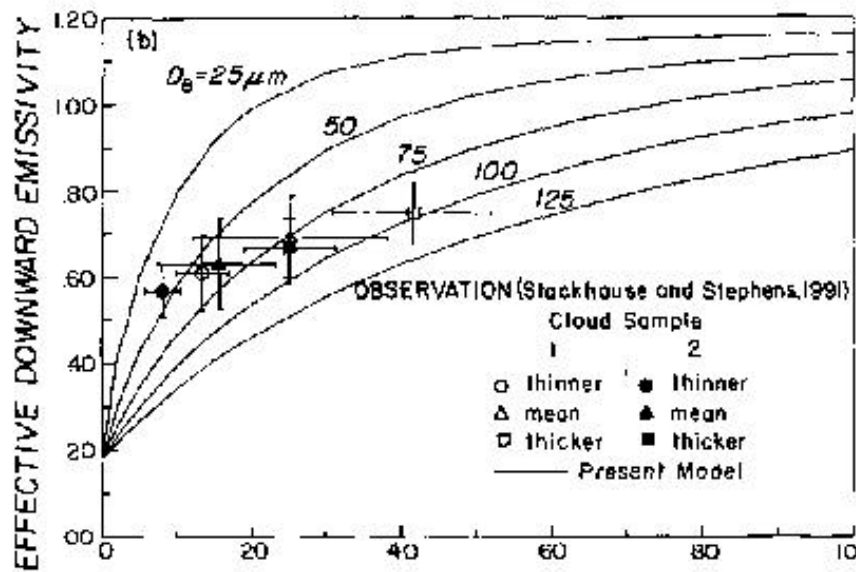
Effect on effective particle size



- Effective particle sizes are not consistent for the same size distributions used in CERES and MODIS algorithms

Effect of particle size on emissivity and albedo

Fu and Liou 1993



- Particle size effect is significant for both short and long wave radiation

Parameterization for Hexagonal Columns

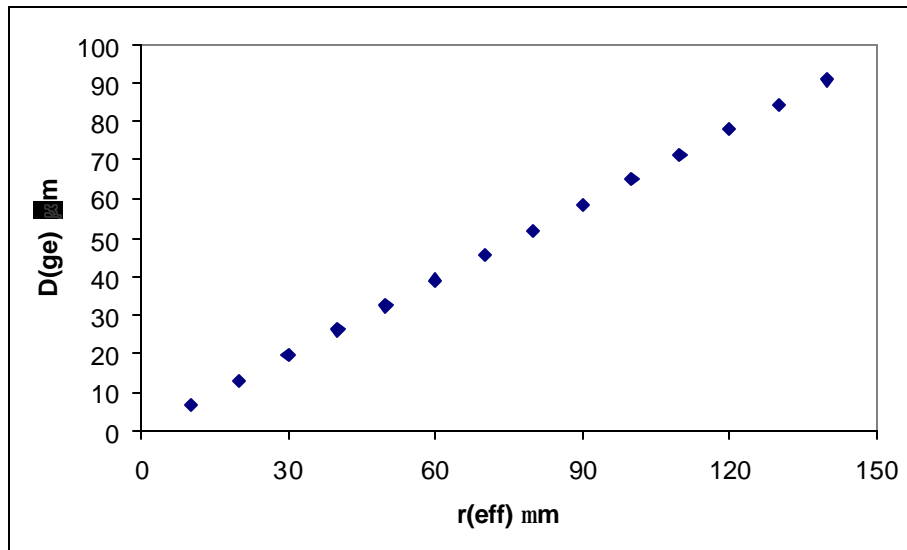
$$\beta = \text{IWC}(a_0 + a_1/D_{ge}), \quad (3.9a)$$

$$1 - \tilde{\omega} = b_0 + b_1 D_{ge} + b_2 D_{ge}^2 + b_3 D_{ge}^3, \quad (3.9b)$$

$$g = c_0 + c_1 D_{ge} + c_2 D_{ge}^2 + c_3 D_{ge}^3, \quad (3.9c)$$

$$f_{\delta} = d_0 + d_1 D_{ge} + d_2 D_{ge}^2 + d_3 D_{ge}^3, \quad (3.9d)$$

$$D/L = \begin{cases} 1.0 & 0 < L \leq 30 \text{ } \mu\text{m} \\ 0.8 & 30 < L \leq 80 \text{ } \mu\text{m} \\ 0.5 & 80 < L \leq 200 \text{ } \mu\text{m} \\ 0.34 & 200 < L \leq 500 \text{ } \mu\text{m} \\ 0.22 & L > 500 \text{ } \mu\text{m}, \end{cases}$$



$$r_g = \frac{3(3)^{1/2}}{8} D_{ge}. \quad (3.12)$$

- Fu (1996) developed parameterization scheme for hexagonal columns (CERES algorithm)

Parameterization for mixed habits

50% bullet rosettes, 25% plates and 25% hollow columns

$L < 70 \mu\text{m}$

30% aggregates, 30% bullet rosettes, 20% plates and 20% hollow columns $L > 70 \mu\text{m}$

$$\beta = a_o/D_e, \quad a_o = 3.276 \text{ m}^2 \text{ g}^{-2} \mu\text{m}, \quad (17)$$

$$1 - \omega = b_o + b_1 D_e + b_2 D_e^2, \quad (18)$$

$$g = c_o + c_1 D_e + c_2 D_e^2, \quad (19)$$

$$D_{ge} = \frac{2\sqrt{3}}{3} \frac{C}{\rho_{ice} A}, \quad (20)$$

$$D_{ge} = 0.77 D_e. \quad (21)$$

Table 2. Coefficients for the Parameterizations for ω and g Using Equations (18) and (19)^a

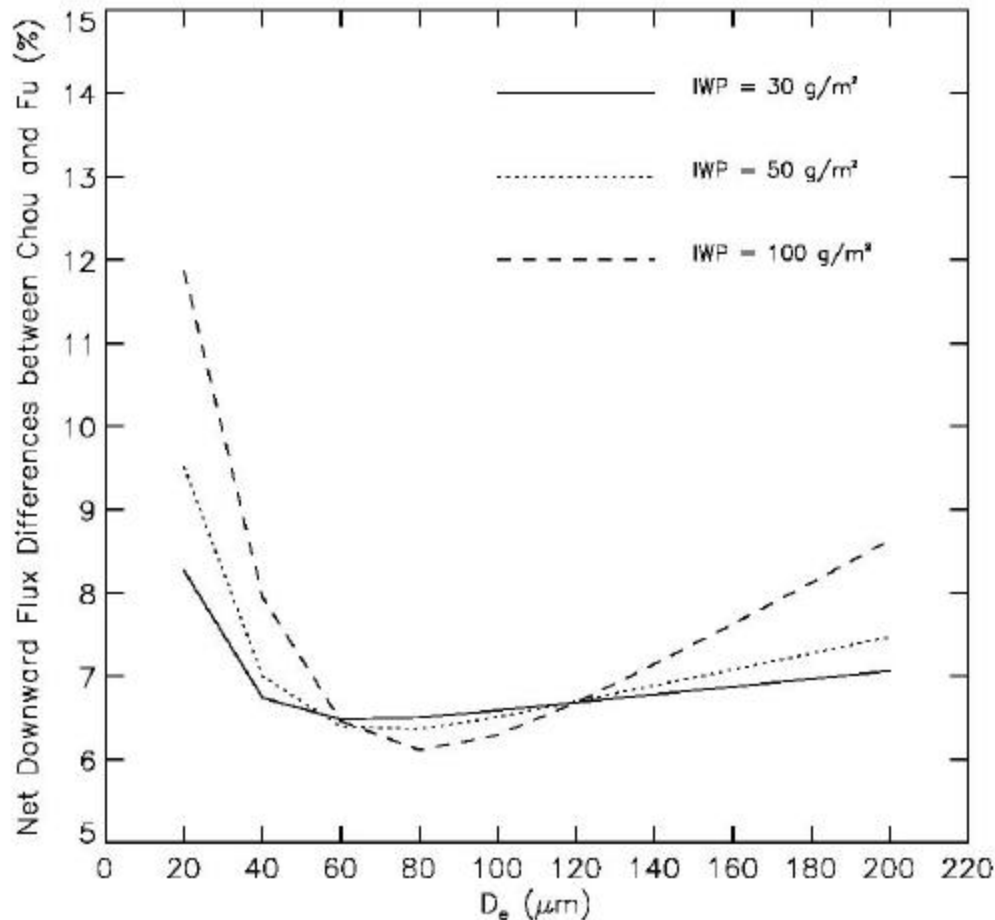
Band	b_o	b_1	b_2	c_o	c_1	c_2
6	1.37e-07 ^b	7.06e-08	5.64e-12	7.56e-01	1.08e-03	-4.12e-06
7	1.37e-07	7.06e-08	5.64e-12	7.56e-01	1.08e-03	-4.12e-06
8	-1.52e-07	7.38e-08	-3.48e-11	7.46e-01	1.41e-03	-5.74e-06
9	1.41e-06	5.72e-06	-1.22e-09	7.25e-01	1.85e-03	-7.73e-06
10	1.12e-03	5.65e-04	-8.96e-07	7.17e-01	2.28e-03	-8.86e-06
11	4.83e-02	2.74e-03	-9.02e-06	7.71e-01	2.45e-03	-1.00e-05

^aThe unit of D_e in equations (18) and (19) is give in μm .

^bRead 1.37e-07, for example, as 1.37×10^{-7} .

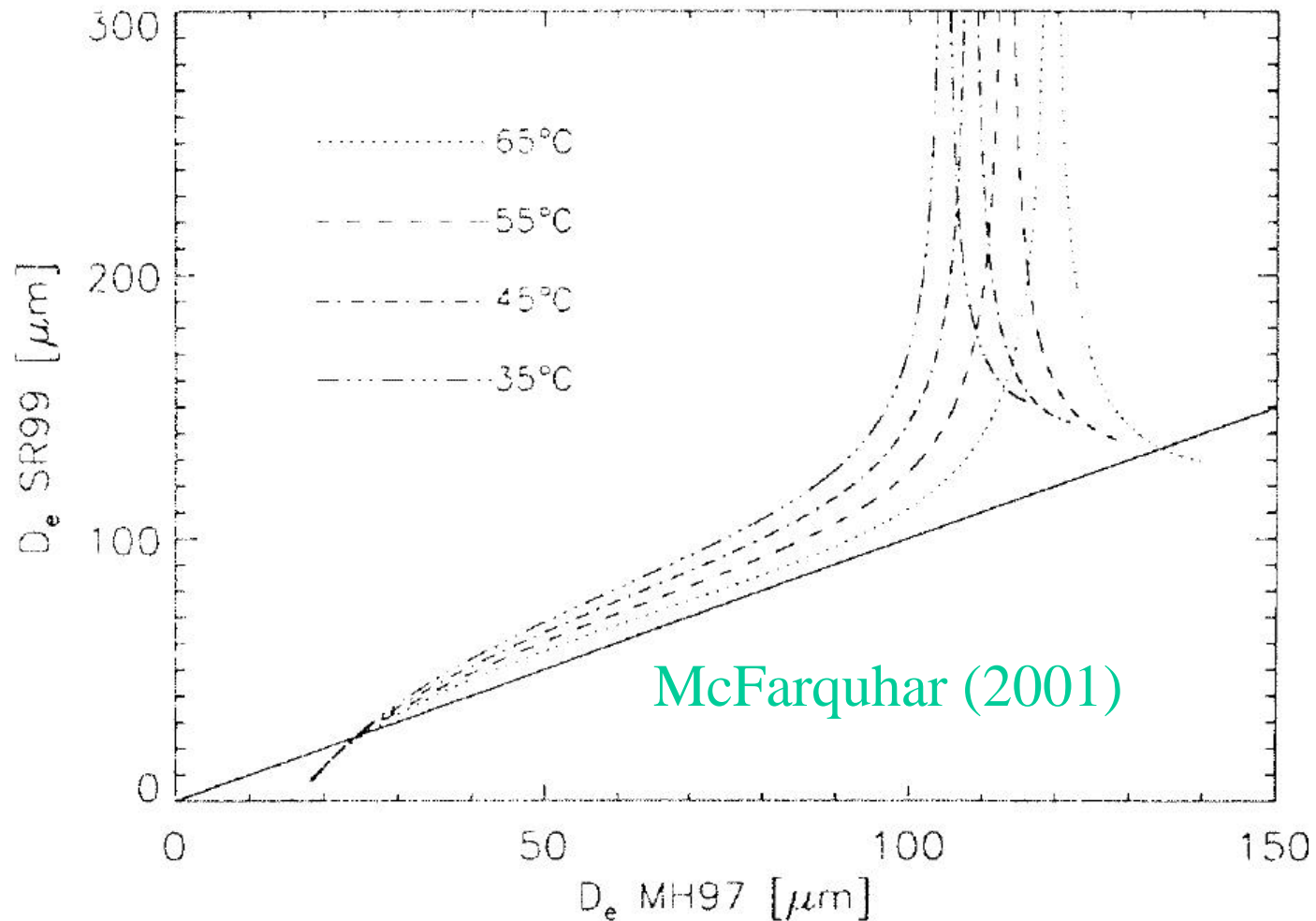
- Chou et al. (2002) developed parameterization for mixed crystal habits (MODIS algorithm)

Effects on net downward flux density



- Even for the same D_e , different assumptions of crystal shapes lead to large gaps in calculated net downward flux density – D_e and habits are both needed

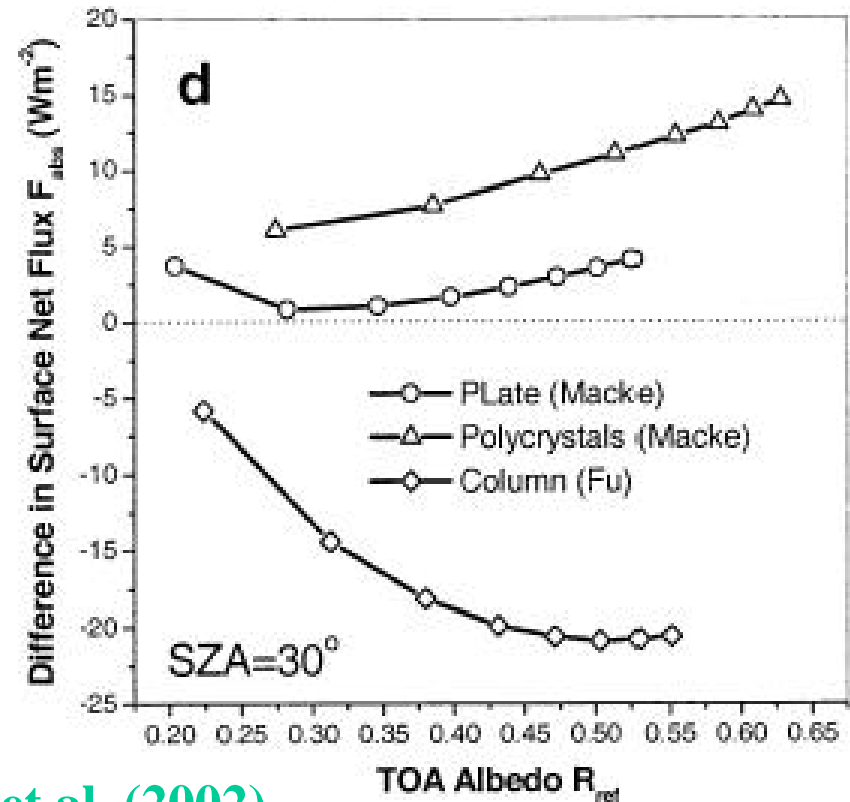
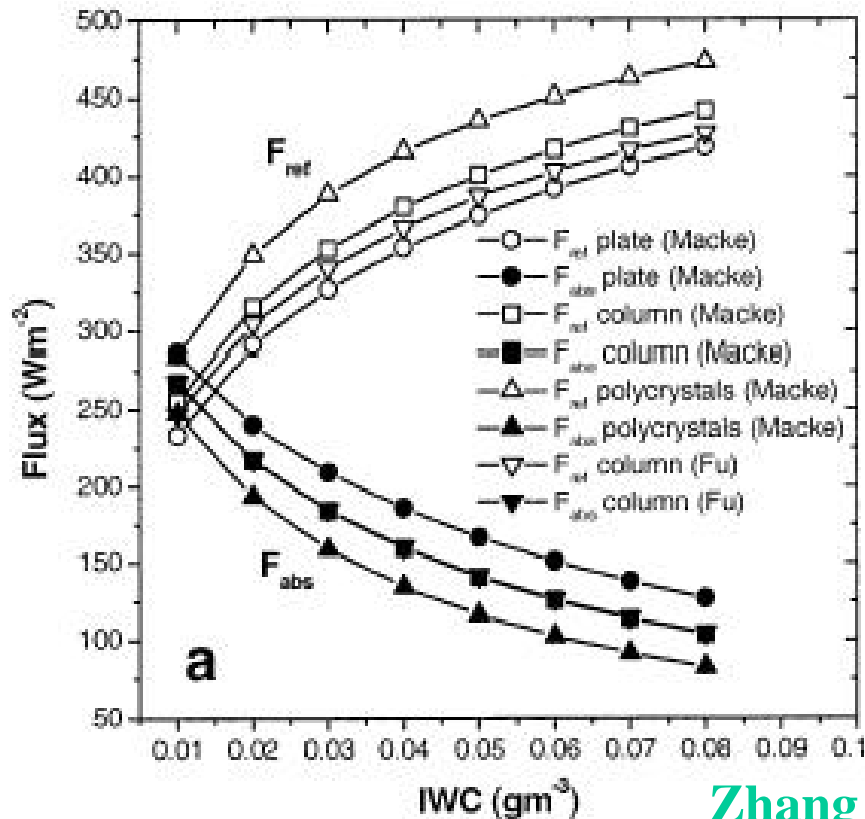
Crystal habit effect on cloud schemes



- Ice cloud parameterization schemes become habit specific

Effect of Crystal Shape on SSRB

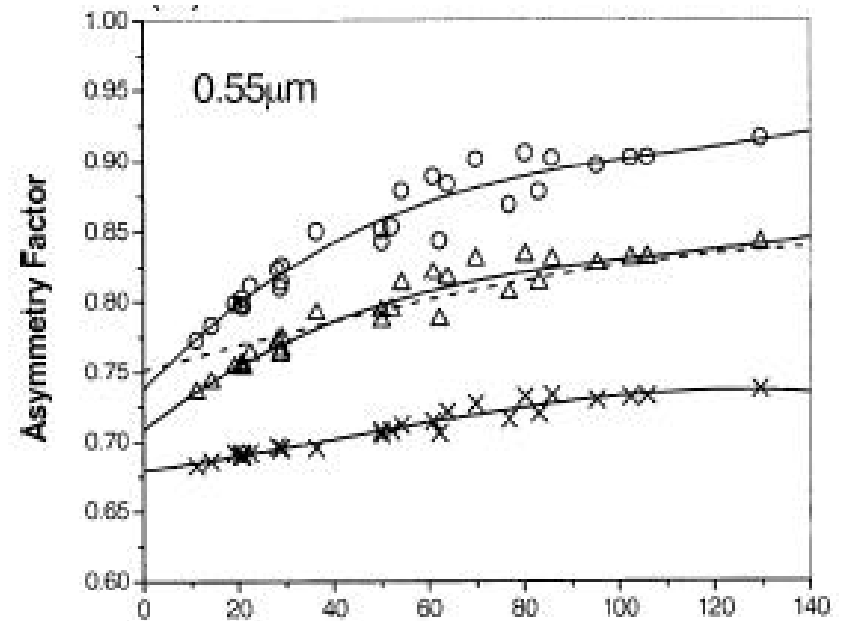
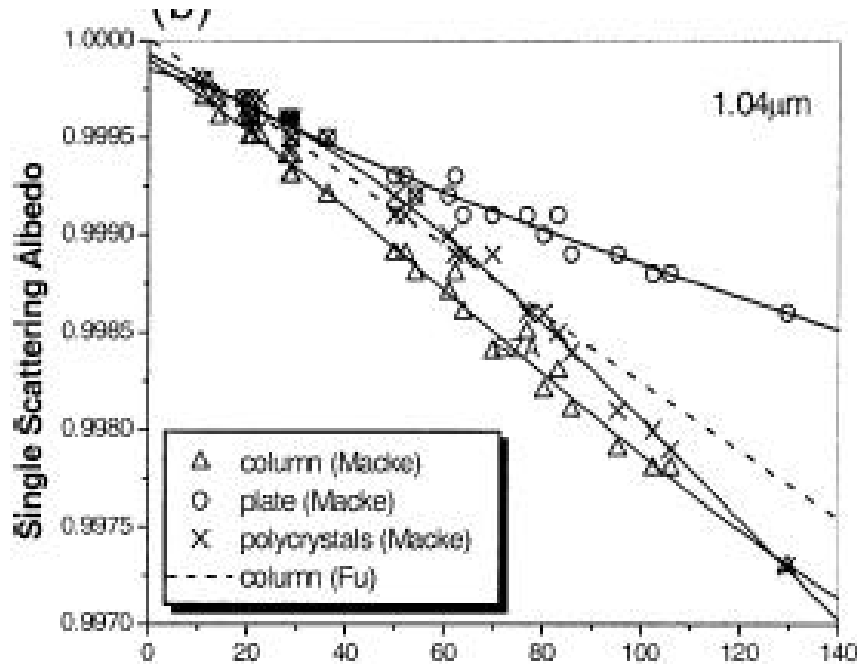
$$D = \begin{cases} 0.142L^{0.7556} & \text{when } L \leq 30 \mu\text{m}; \\ 0.064L^{0.53} & \text{when } L > 30 \mu\text{m}. \end{cases}$$



Zhang et al. (2002)

- Different aspect ratios and surface roughness lead to significant changes of net flux density at the TOA and at surface.

Effects on single scattering properties



Zhang et al. (2002)

- Single scattering properties vary due to changes in aspect ratios

Crystal habits vary dramatically from case to case

Table 3. Summary of Case Study Results

Date, dd mm yy	Time, UTC	Class				Reflectance Level, %			
		A	B	C	D	30–45	45–60	60–75	75–90
01 10 99	1645 ^a	o						x	x
31 10 99	1700			o				x	
10 03 00	1630			o					x
	1700		o	o				x	x
	1730		o	o				x	x
	1730	o	o				x		
11 03 00	1600 ^a			o	o			x	x
	1630 ^a			o				x	x
	1700 ^a		o					x	
	1730 ^a		o	o				x	
12 03 00	1600			o	o		x	x	
	1630		o	o			x	x	
	1700		o	o			x	x	
	1730	o					x	x	
13 03 00	1600		o	o		x			
	1700	o	o			x			
	1730	o	o			x			
14 03 00	1600			o	o		x	x	x
	1630		o	o				x	x
	1630	o	o				x		
	1700	o	o				x	x	x
	1730	o	o				x	x	x
26 08 00	1622	o	o	o					x
	1652	o	o	o					x
27 08 00	1622	o	o	o					x
	1652 ^a	o	o	o					x
27 08 00	2050		o	o			x	x	
28 08 00	1652		o	o					x
05 09 00	2055 ^a		o	o			x	x	

^aCases presented in figures.

A: ISCCP --Polycrystals (42.5%)

B: MODIS--Rosettes(75.0%)

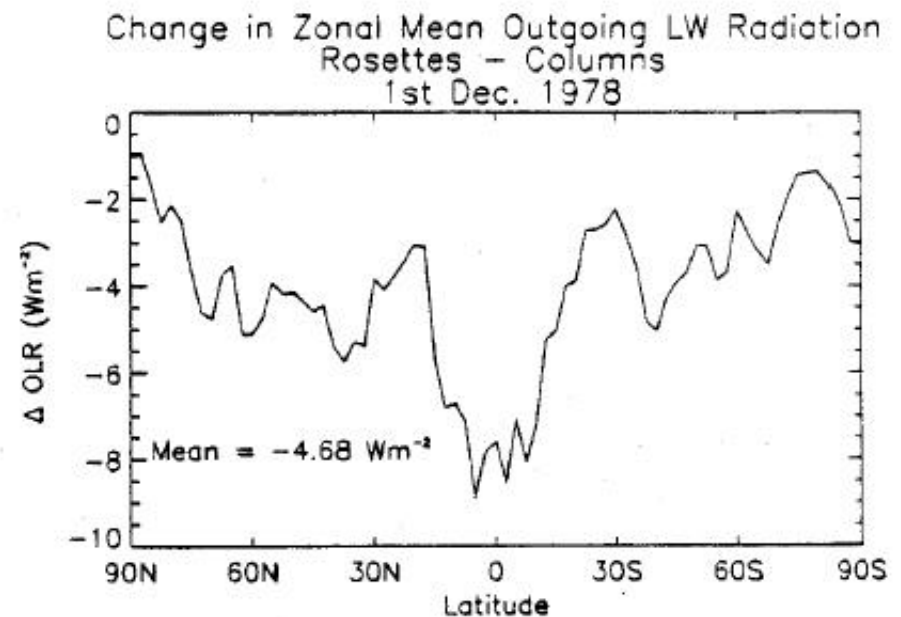
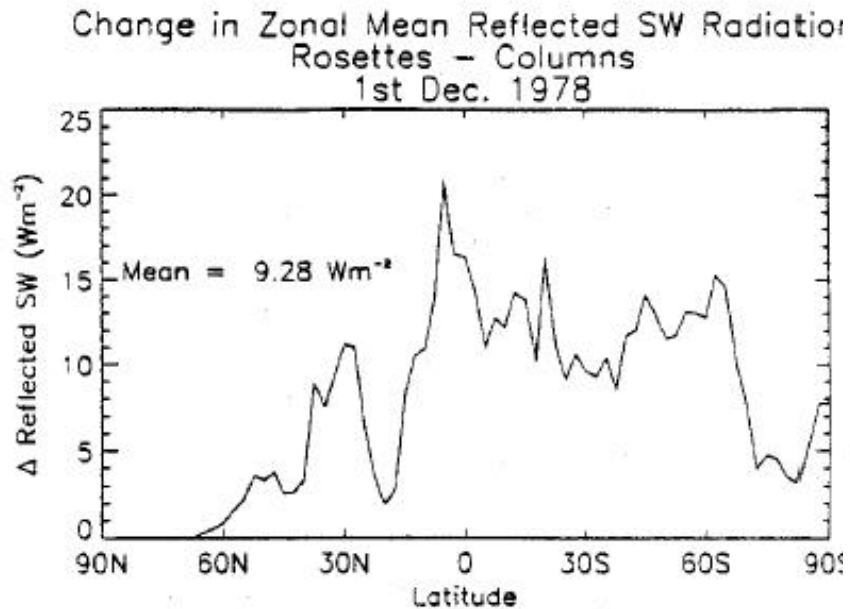
C: CERES – Columns (71.4%)

D: Spheres (10.7%)

Chepfer et al. (2002)

- 28 pairs of pixels by GOES, AVHRR, and VIRS data show that CERES and MODIS algorithms can represent the crystal habits in most cases

Effects on zonal mean SW and LW radiation



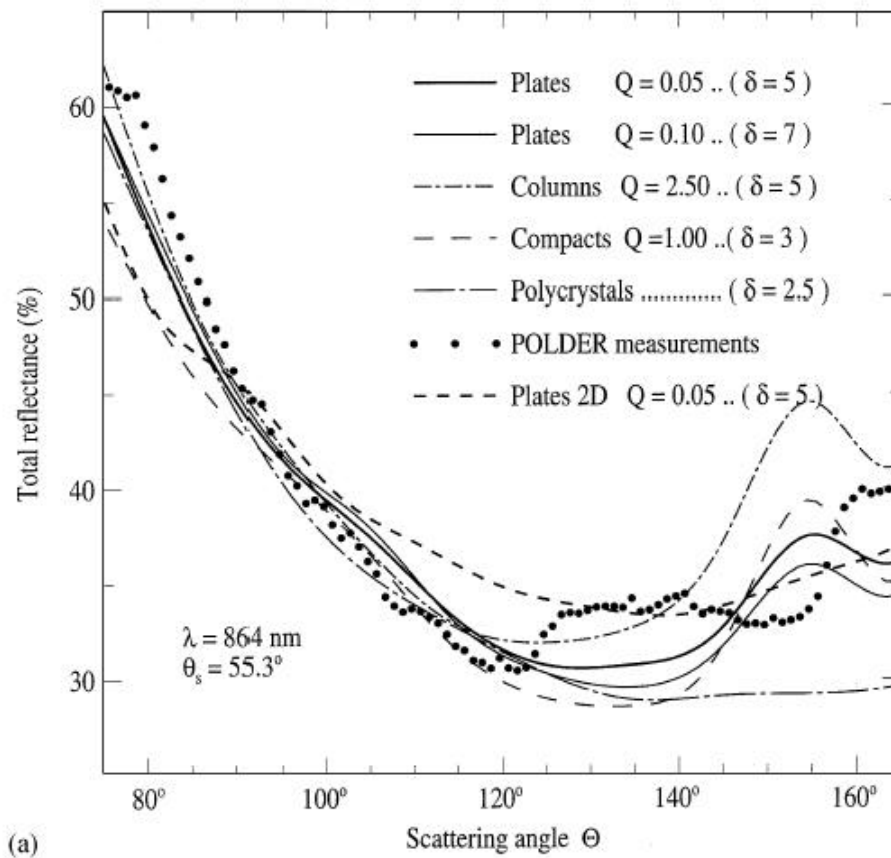
Mitchell 1997

- By changing from hexagon columns to bullet rosettes, net radiation budget at the TOA varies by more than 10 W m^{-2} , with different zonal mean changes

Retrieval method for crystal habits

- All based on angular distributions of reflected intensity
- Problems:
 - lack of observations at ideal angles
 - critically based on plane-parallel assumption which is not verified during the observation
- Non-restricted biaxial data from CERES overcomes these problems

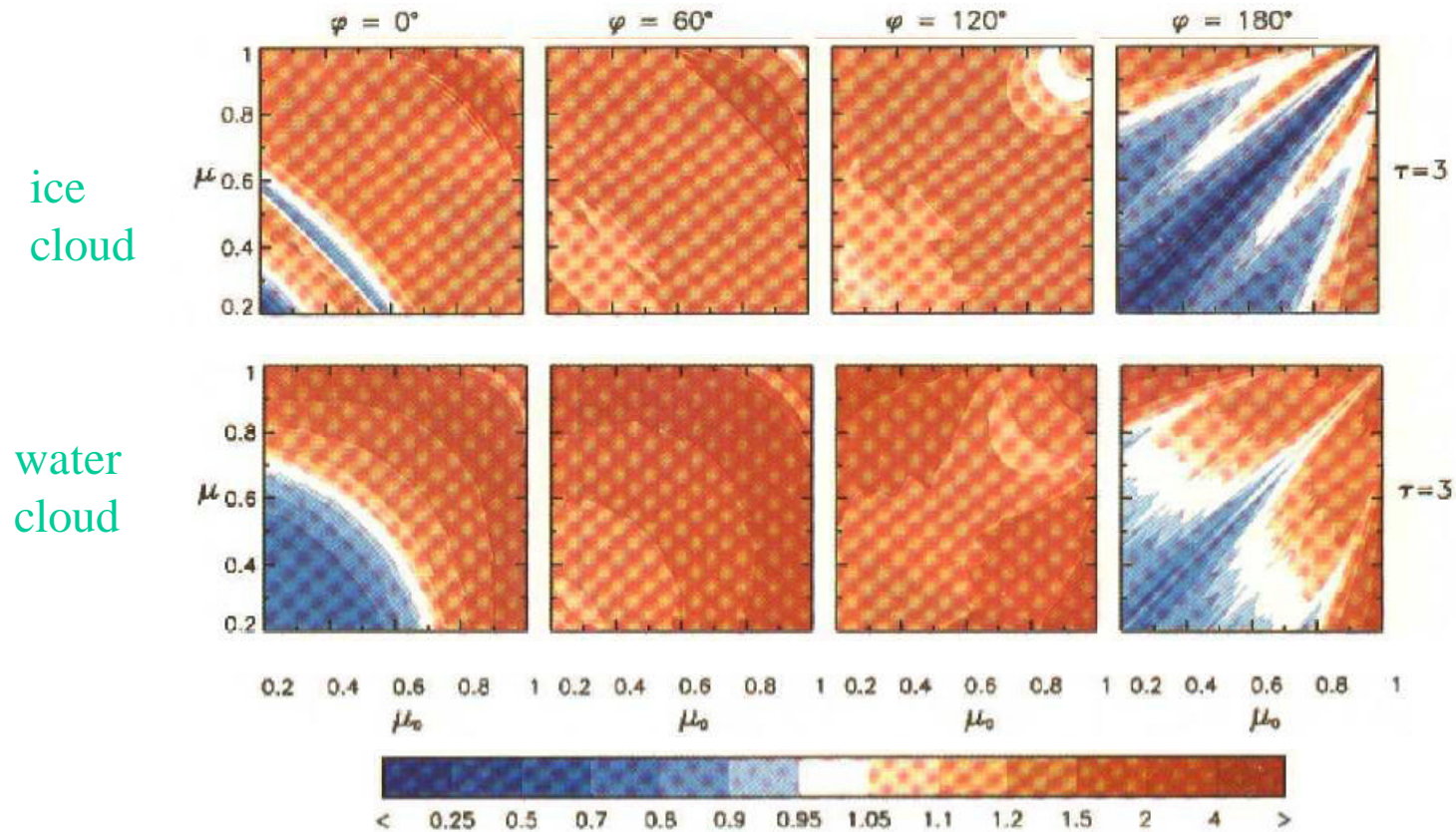
Current methods are based on information from multi-view



Chepfer et al. 1998

- Similarity for various shapes in most scattering angles (60° and $\sim 180^\circ$)
- Plane-parallel assumption is critical in these methods

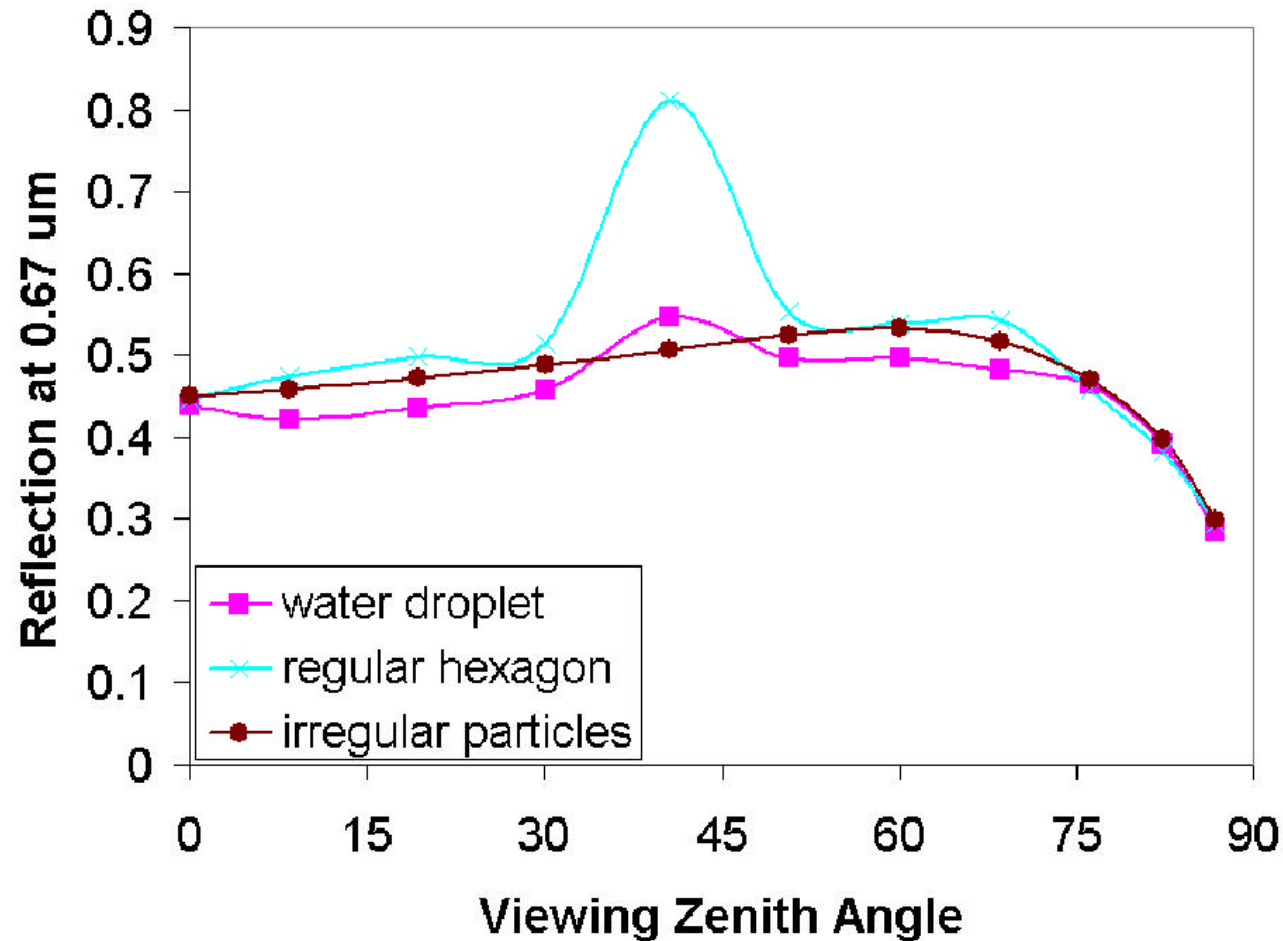
Discriminating shapes by enhanced backscattering



Mishchenko et al. 1996

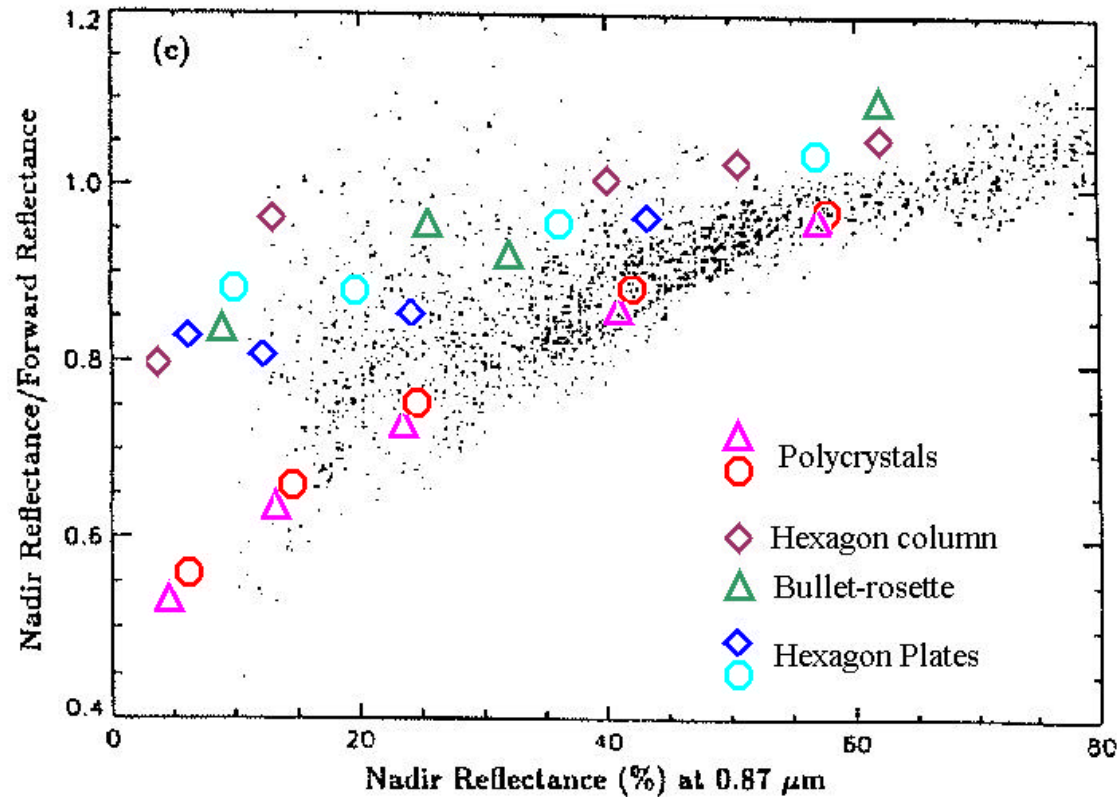
- Similar results were obtained by others

Discriminating shapes by enhanced backscattering



- Behaviors of water droplet and different ice crystals (SZA=40°)

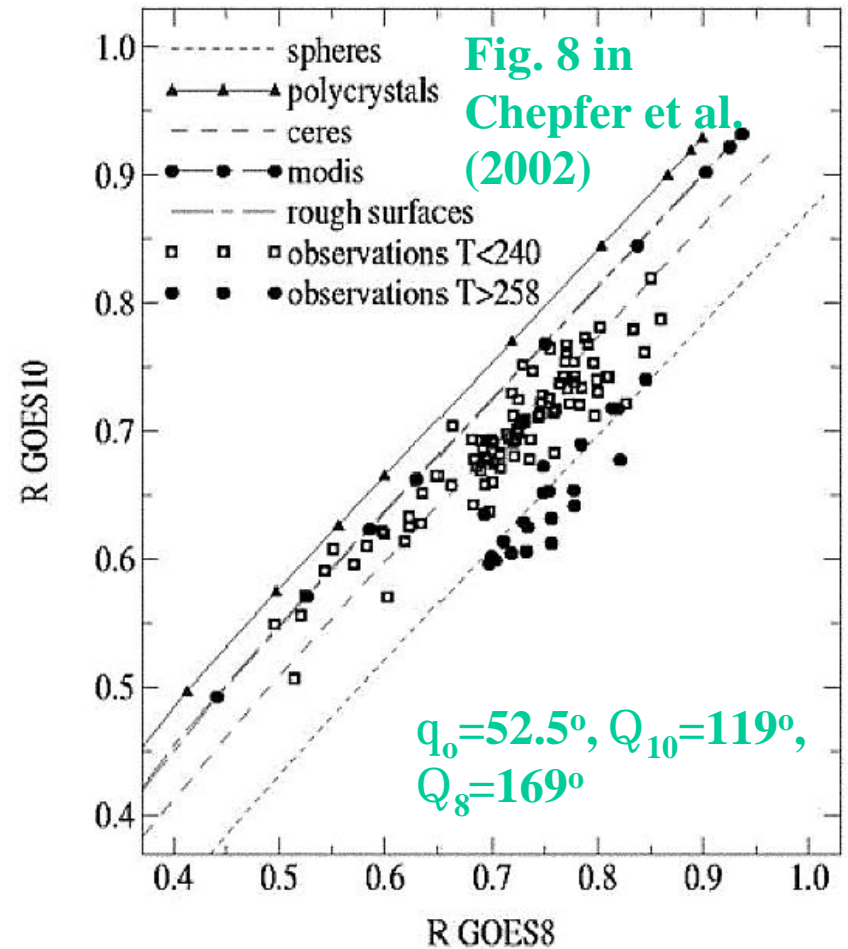
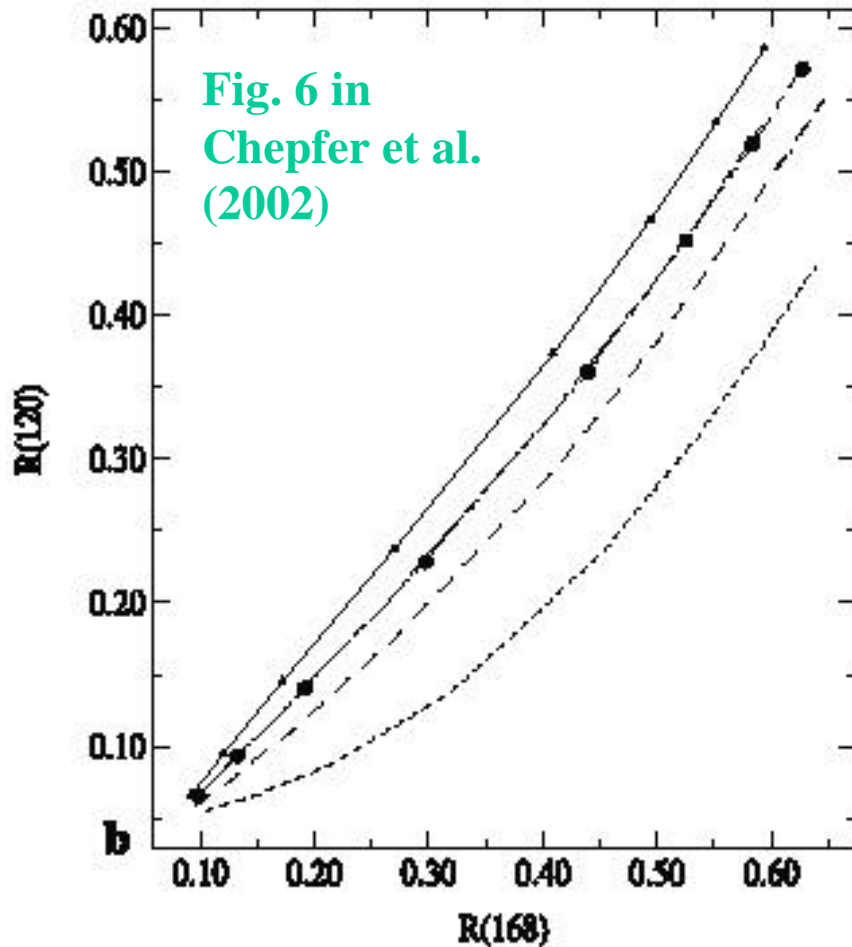
The ideal pair of angles are scarce in satellite data



- From ATSR, Baran et al. (1998) found a case with $Q=157^\circ$ and 65° using ATSR data

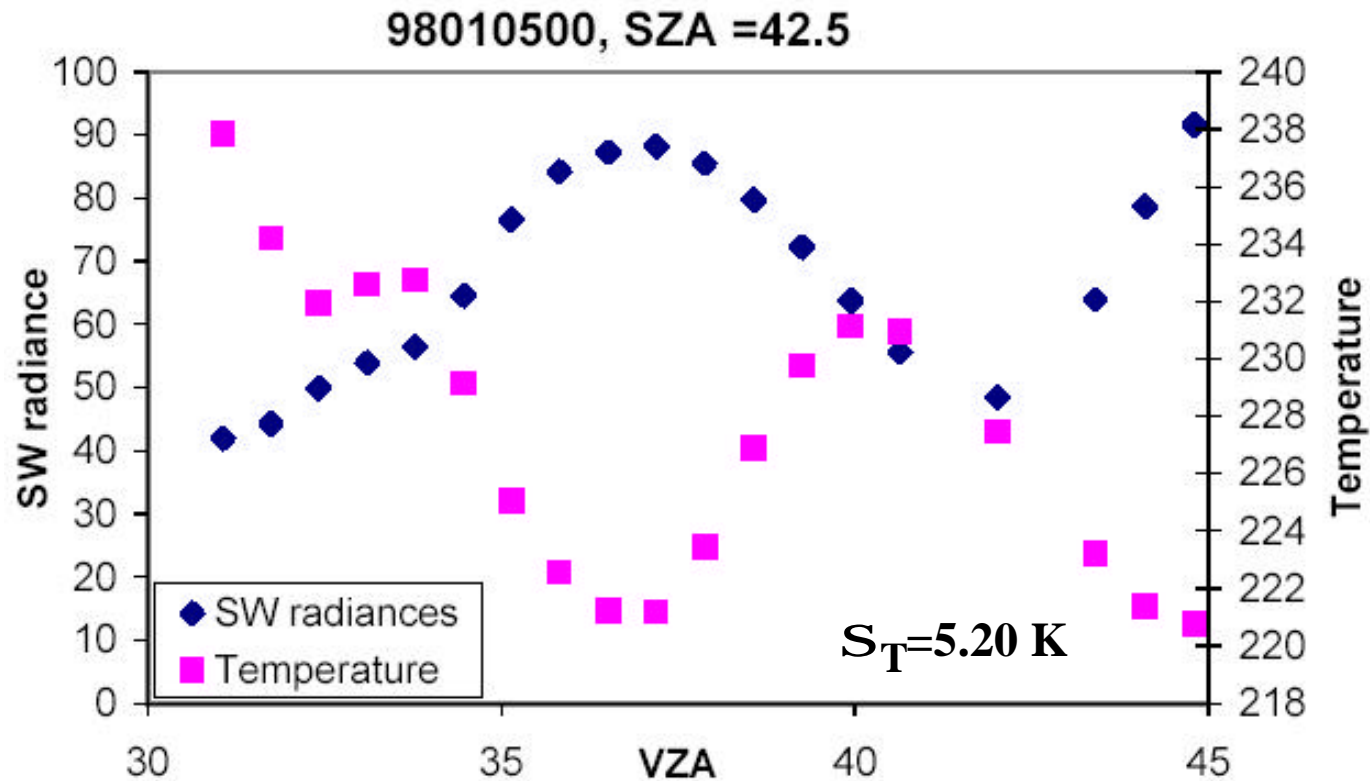
Multisatellite Approach

($\theta_s=60^\circ$)



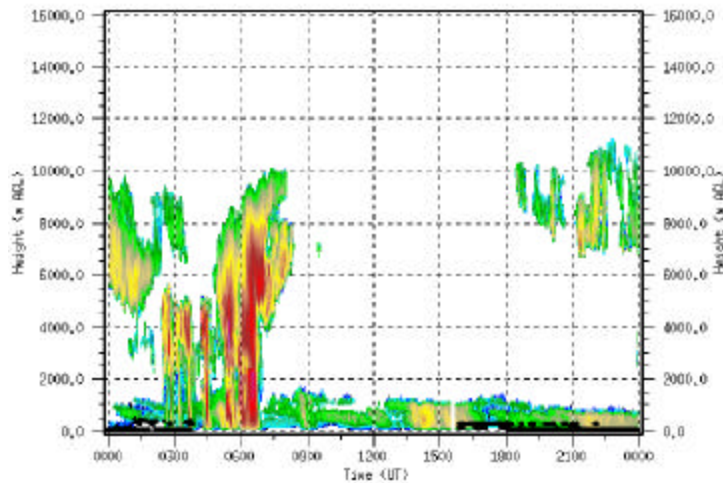
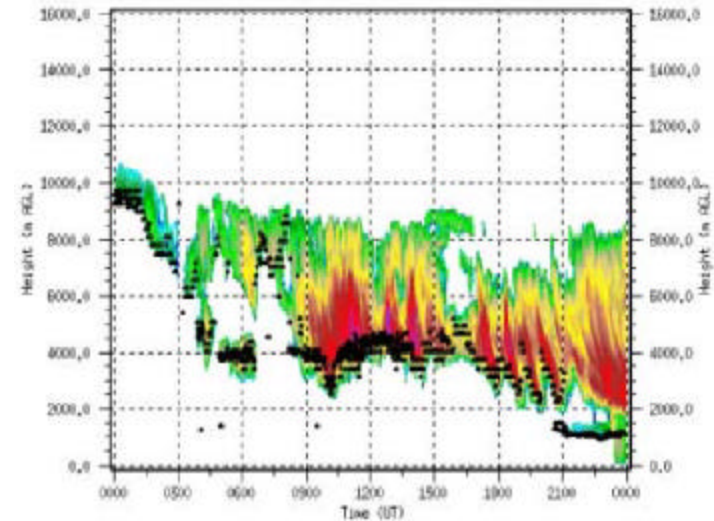
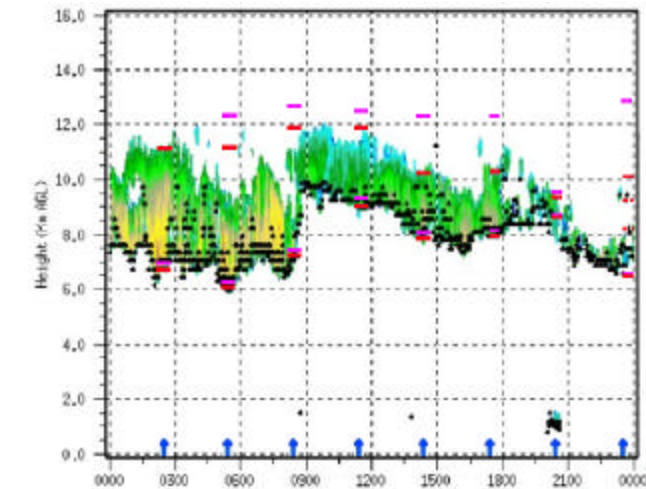
- Data from different satellites are used to obtain ideal viewing angle pairs.

Effect of cirrus morphology



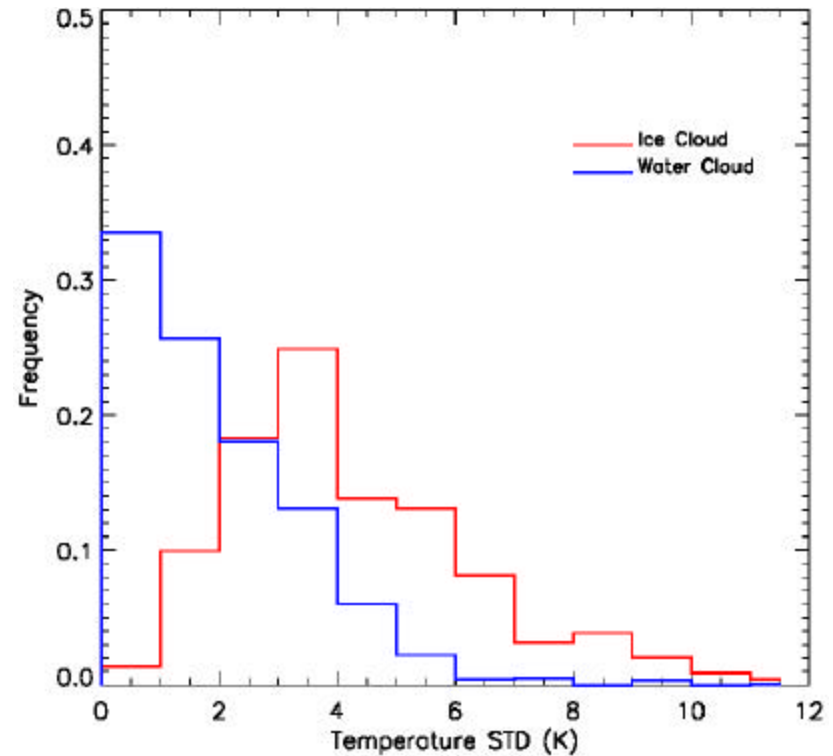
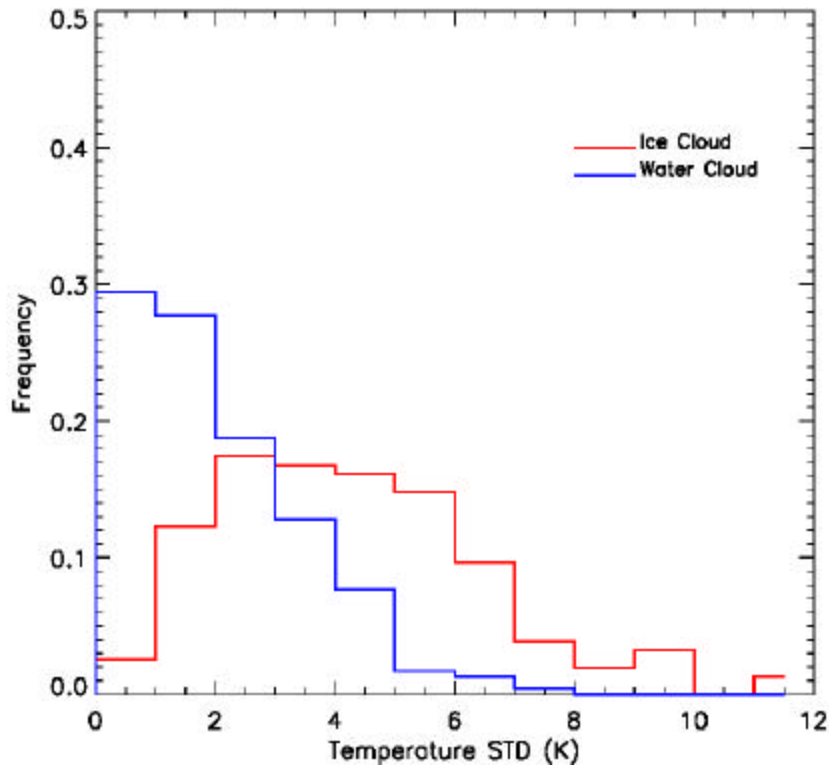
- Cirrus morphology plays a dominant role in controlling angular distribution of reflected solar energy

Examples of Cirrus Morphology



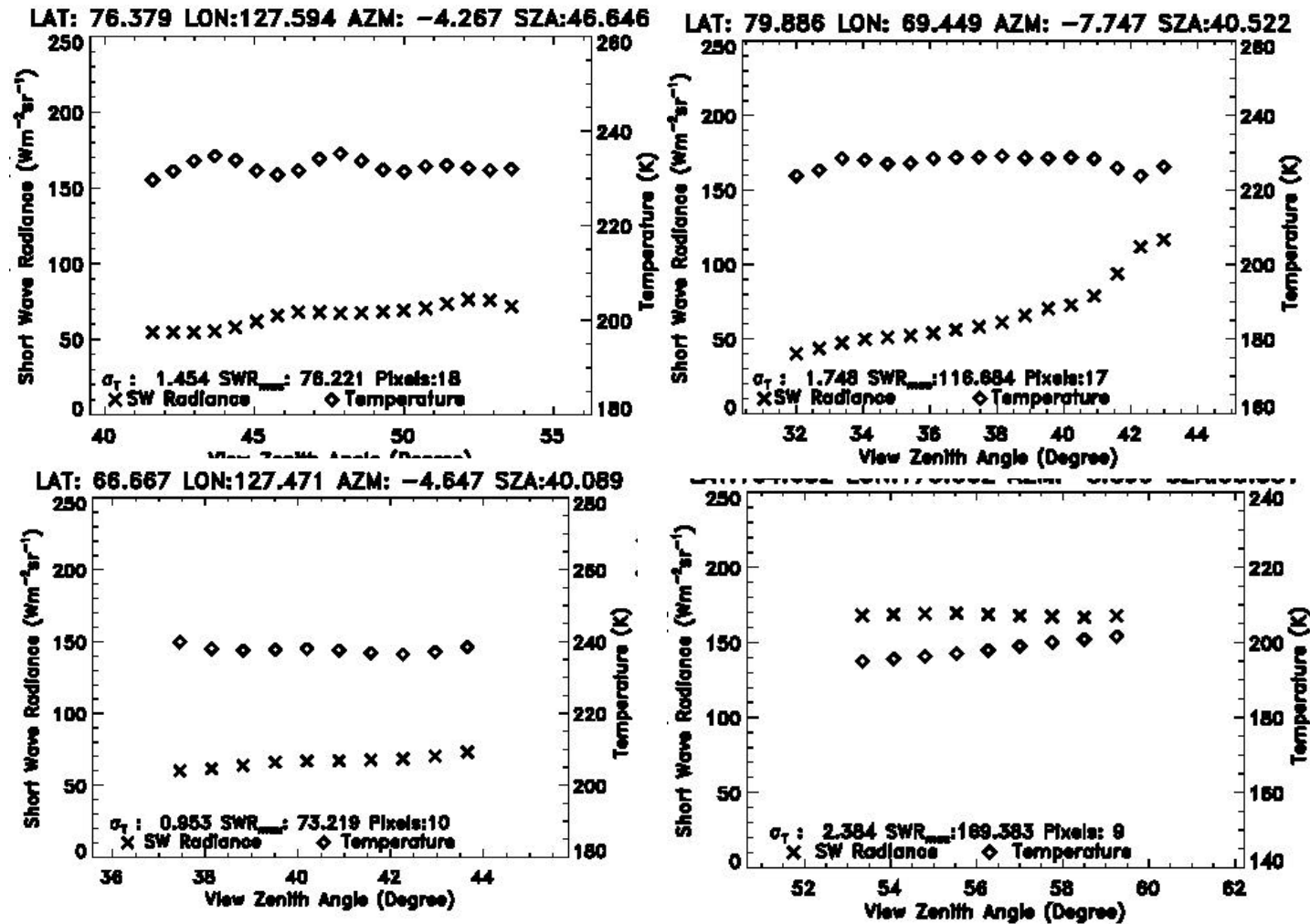
- Typical cirrus morphology observed by radar echoes

Indication of departure from plane-parallel: standard deviation of cloud top temperature



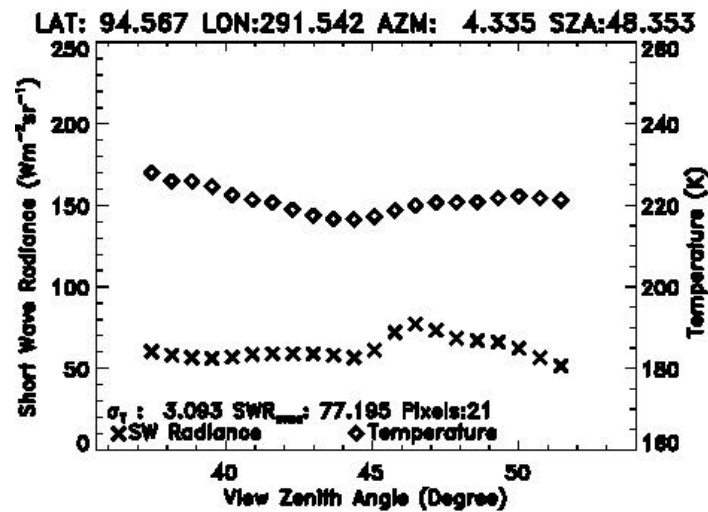
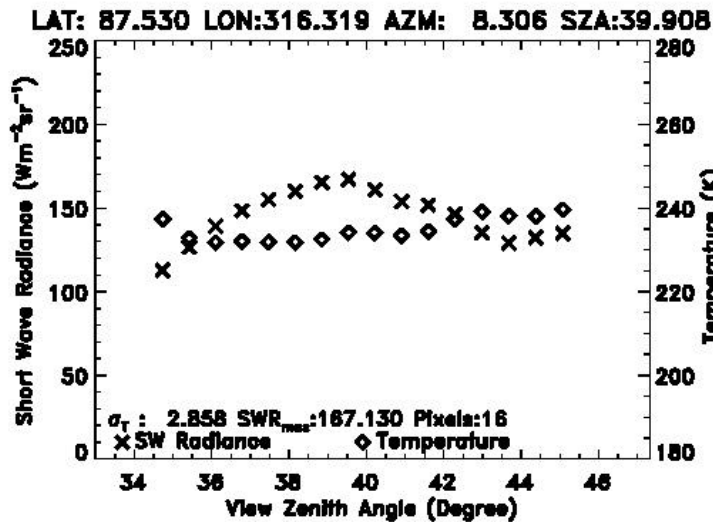
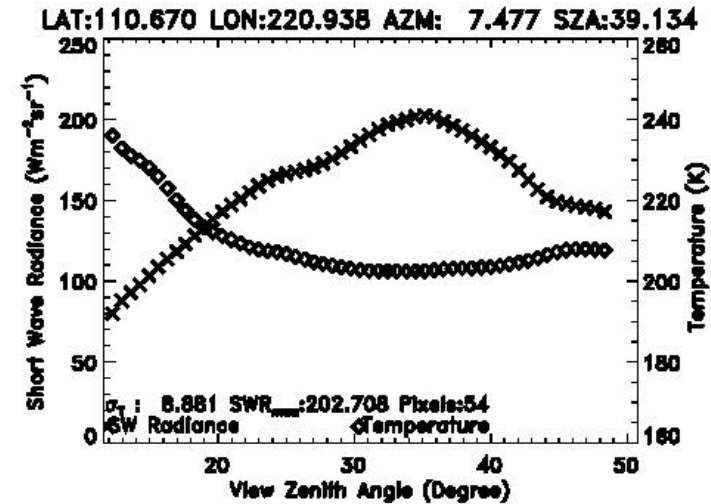
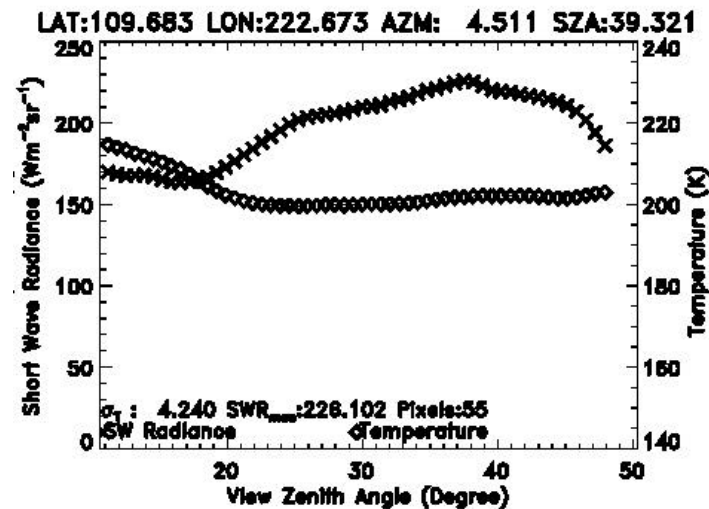
- Comparing with water clouds, cirrus morphology is a much more serious problem.

Examples of Polycrystal



- Crystal habits can be derived for cirrus scene with small temperature variations.

Examples of Hexagon



- Crystal habits can be derived for cirrus scene with small temperature variations.

Summary

- Theoretical size distribution can improve the consistency in the retrieved results
- Lack of knowledge in crystal habits leads to significant uncertainties in radiative properties of ice clouds
- Previous efforts in determining crystal habits may be influenced by cirrus morphology
- Unrestricted biaxial data of CERES contain are ideal for deriving information of crystal habits